

Near Field RFID Sensing and Imaging

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Abstract

There is a growing need for designing small self-powered devices, able to sense and deliver accurate information on the field distribution around or inside complex media for monitoring and imaging purposes. Industrial, Scientific and Medical sensing and imaging applications basically rely on the measurement of the diffracted field distribution created by an illuminating field. In most cases this information is only available at a set of accessible check points, using either an array of sensors or a moving probe. The requirements of RF or DC cabling sets necessary reduce the flexibility and increase the cost and complexity of the measurement system. Additionally some times the points of interest lie in locations that are physically inaccessible, or where wiring is not possible. In such cases, it is convenient the use of self-powered solution, that do not require any physical connection to instrumentations in order to retrieve the information, such as RFID-based elements.

1 Introduction

Measuring EM field in a set of points is more and more demanded for different sensing applications. Conventional solutions for accessible points use either a moving probe or an array of sensors needing and RF and/or DC connexion from the final processing point to each of the probes. When this information is required in inaccessible points, where wiring is not a suitable option, completely wireless sensors are required. Such sensors usually present a battery, and therefore a short lifetime. An attractive alternative consists on using powering energy scavenged from external sources, such as incident electromagnetic waves. In this paper we introduce the use of passive RFID tags, which perform EM scavenging to power up, in order to perform unlimited time sensing measurements.

2 RFID Principle of Operation

RFID communication is based in the modulation of the scattered signal by an RFID tag; RFID tags do not transmit information in the conventional way, that is by actively feeding a modulated signal into the tag antenna, but rather they modulate the amount of power that is reflected back to a reader, what is called as backscattering modulation. It is known that the reflection of any antenna, for instance an RFID tag, can be decomposed in two terms, the first is dependent of its structure (structural mode scattering, $b_{structural}$), and the second also depends on its load (antenna mode scattering, b_{AM}). By properly changing the antenna load between two different impedances (Z_{L1} and Z_{L2}), the reflected signal is modulated, and thus marked in a clear way from any background reflection. This principle of operation is the same of the modulation scattered technique (MST) [1].

For any linear and isotropic media, it is possible to define a reciprocity based formulation for the reflected differential signal as [2]:

$$\Delta\rho_{in} = \rho_{in}|_{Z_L=Z_{L_1}} - \rho_{in}|_{Z_L=Z_{L_2}} = -\frac{Z_{tr}}{2R_T}\Delta\tilde{\rho}_L \quad (1)$$

where Z_{tr} is the transfer impedance which relates the open circuit voltage at the tag to the radiated power by the reader ($Z_{tr} = \frac{V_{OC}^2}{2P_a}$), R_T is the resistance of the RFID tag antenna, and $\Delta\tilde{\rho}_L$ is the differential complex reflection coefficient, which has a straightforward relation with the load impedances:

$$\Delta\tilde{\rho}_L = \tilde{\rho}_{L_1} - \tilde{\rho}_{L_2} = 2R_T \frac{Z_1 - Z_2}{(Z_1 + Z_T)(Z_2 + Z_T)} \quad (2)$$

where $\tilde{\rho}_L$ refers to the complex reflection coefficient defined as: $\tilde{\rho}_L = \frac{Z_L - Z_T^*}{Z_L + Z_T^*}$. For a free-space scenario, and under the assumption of far-field, (1) can be approximated using the radar cross section (RCS) of the RFID tag:

$$|\Delta\rho_{in}|^2 = \frac{\lambda^2 G_R^2}{(4\pi)^3 r^4} \Delta\sigma_T^{AM} = \left(\frac{\lambda}{4\pi r}\right)^4 G_R^2 G_T^2 |\Delta\tilde{\rho}_L|^2 \quad (3)$$

where $\Delta\sigma_T^{AM}$ is the differential radar cross section [3] of the tag in both states, directly related to $\Delta\tilde{\rho}_L$. Backscattered modulation makes RFID a suitable candidate for EM-field sensing purposes; moreover, due to its battery-less nature (passive RFID tags), no extra cabling is required to generate the modulation, increasing its flexibility, over other schemes.

3 RFID Based EM-field Sensing

In order to measure the field in a region, it is necessary the use of small sensors, able to retrieve the field distributions without disturbing it; as it has been said in the previous section, MST is a natural solution for field measurement, because it does not require of RF bulky connections between the probes and the receiver, although they require of some methodology to start the modulation (DC wiring schemes, optical activation, etc.). Passive RFID tags, can be used as MST probes, and due to the absence of battery, they do not require external instrumentation to activate the modulation. Nevertheless, the rectifying circuit that exists in the RFID IC, which collects the power required for its operation, introduces a non-linear behaviour in its input impedance, and this must be taken into account for EM-field measurement through a calibration procedure. This calibration, shortly described in [4], consists in the characterization of the non-linear behavior of $\tilde{\rho}_{L_2}$, through the measurement of relative variation of $\Delta\rho_{in}$ for a reference position (r_{ref}) when the incident power upon the tag is changed in a known way. The curve that is obtained ($S = \frac{\Delta\rho_{in}^S}{\Delta\rho_{in}^{ref}}$) can be used to correct a field measurement by solving:

$$\frac{\Delta\rho_{in}}{\Delta\rho_{in}^{ref}} = \frac{Z_{tr}}{Z_{tr}^{ref}} \cdot S \left(\frac{Z_{tr}}{Z_{tr}^{ref}} \right) \quad (4)$$

It should be noted that the relative field distribution is related to the transfer impedance as:

$$\frac{Z_{tr}}{Z_{tr}^{ref}} = \left(\frac{V_{OC}}{V_{OC}^{ref}} \right)^2 = \left(\frac{E}{E^{ref}} \right)^2 \quad (5)$$

A set of measurements for measuring the field distribution of a ridged horn antenna have been done, where the activation of the RFID modulation is triggered by sending the proper *QUERY* word to the RFID tag through the horn antenna. Figs. 1, and 2 show the results of the field measurement at the E and H-plane of the aperture of the ridged horn antenna, when using a **ALN-9529 Squiggle** commercial tag.

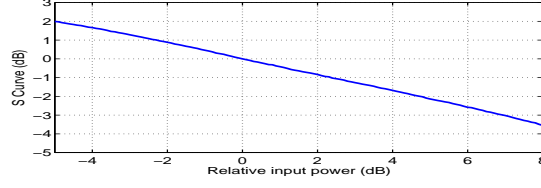


Figure 1: Measured S curve that characterizes the non-linearities of the RFID tag

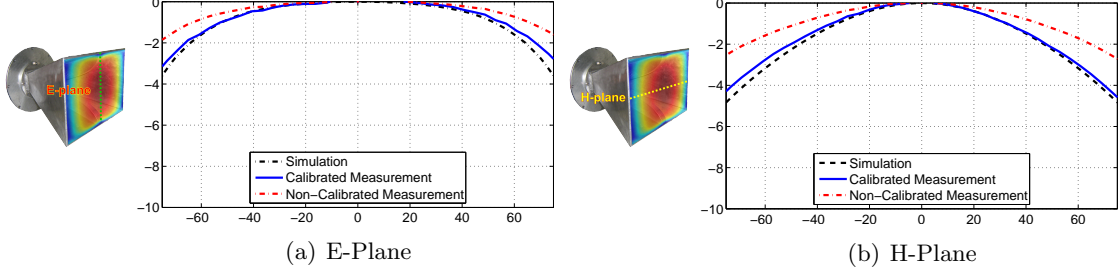


Figure 2: Measurement results compared to the simulation field distribution

4 Temperature Monitoring

Many dielectric media, e.g. water, have a strong dependence of its dielectric properties with the temperature. For instance, the permittivity of water at $3GHz$ changes from $\epsilon_r = 80$ to about $\epsilon_r = 52$ for a variation from $0^\circ C$ to $100^\circ C$, see Fig. 3. Therefore a change in temperature introduces a variation of the propagation characteristics of electromagnetic waves, such as the wavenumber and the attenuation levels, and that can be tracked through the measurement of the variation of a signal that travels through the medium. Additionally, it is well known that the permittivity of the medium surrounding an antenna affects its characteristics, and specially its input impedance. The immersion equation [1, 5], allows to obtain the input impedance of a given antenna when it is used in a different medium, as a function of its frequencial response:

$$Z(\omega_o, \epsilon_r^A) = \frac{1}{m} Z(m\omega_o, \epsilon_r^B) \quad (6)$$

where $m = \sqrt{\frac{\epsilon_r^A}{\epsilon_r^B}}$, is the relative refraction index between the original medium, ϵ_r^B and the new one, ϵ_r^A . This equation can be applied to any antenna, and in particular for RFID tags. Due to the backscattering nature of RFID tags, and the dependence of the reflected signal with $\Delta\tilde{\rho}_L$, a variation of temperature may strongly affect the modulation depth of the RFID response, and therefore can be measured and related to a change in temperature. In order to do so, an RFID antenna has been designed to work inside of water at $25^\circ C$ presenting a good matching with

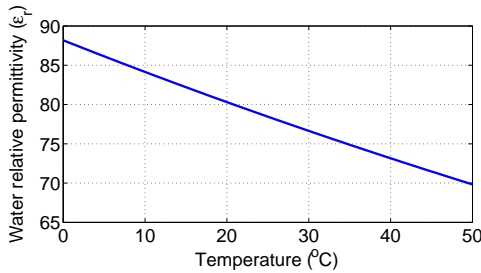


Figure 3: Variation of the permittivity of water with the temperature, according to [6]

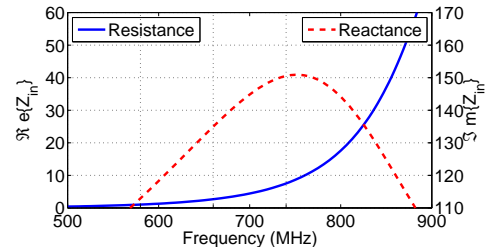


Figure 4: Simulated input impedance of an RFID antenna introduced in water at $25^\circ C$

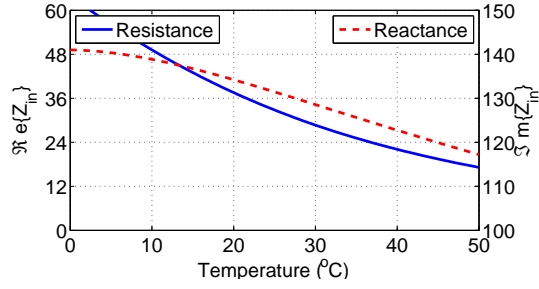


Figure 5: Input impedance at 868MHz in a water tank with variations of temperature

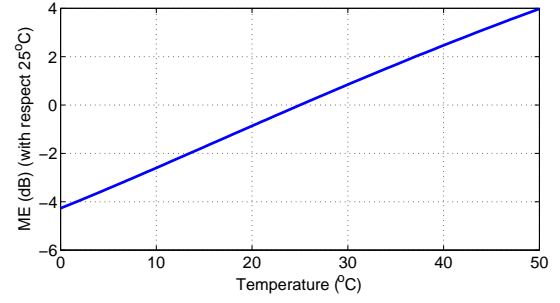


Figure 6: Modulation efficiency with respect to 25°C

an RFID IC *Alien Higgs 2*. Its simulated input impedance is presented in Fig. 4. By using (6), the variation of the input impedance of the tag antenna (Fig. 5) with the temperature can be predicted and used to compute the expected variation of $\Delta\rho_{in}$ (Fig. 6). The simulated results for $\Delta\rho_{in}$ show a noticeable variation of the expected modulation depth for the backscattered signal, for the range of temperatures from 0°C to 50°C , which is a first validation for the concept of temperature tracking using cost-less RFID tags. It is worth mentioning that the predicted variation of the input impedance is such that the amount of power reaching the RFID IC is always above the activation power levels, therefore there exists a response from the tag.

5 Conclusions

In this conference paper it has been shown an initial introduction to the sensing capabilities that RFID present as cost-less sensors. A complete measurement of the relative field distribution of an aperture has been presented, with good agreement in both magnitude and phase with the expected field distribution. Also preliminary results on temperature tracking using RFID tags have been presented, showing that the variation of the magnitudes is such that they allow for a proper tracking, and by using a calibration measurement, it could even lead to a rough estimation of the actual temperature of the medium. Additional results concerning near-field measurements using RFID will be presented at the conference.

Acknowledgments

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